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(73) Patentee: 000153878

Semiconductor Energy Laboratory Co. Ltd.

398, Hase, Atsugi-shi, Kanagawa-ken

(72) Inventor: Shunpei Yamazaki

398, Hase, Atsugi-shi, Kanagawa-ken

Semiconductor Energy Laboratory Co. Ltd.

(72) Inventor: Yasuyuki Arai

398, Hase, Atsugi-shi, Kanagawa-ken

Semiconductor Energy Laboratory Co. Ltd.

(72) Inventor: Satoshi Teramoto

398, Hase, Atsugi-shi, Kanagawa-ken

Semiconductor Energy Laboratory Co. Ltd.

Examiner Mitsuo Kawamoto

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(54) [Title of the Invention] Semiconductor Device, Method of Fabricating Same, and, Electrooptical Device

(57) [What is claimed is:]

1. A semiconductor device comprising:

a film-shaped resinous substrate;

a resinous layer formed on a surface of said resinous substrate; and

thin-film transistors formed on said resinous layer.

2. The semiconductor device of claim 1, wherein the surface of said resinous layer is planarized.

3. The semiconductor device of claim 1, wherein said resinous layer is made from an acrylic resin.

4. A method of fabricating a semiconductor device, comprising the steps of:

forming a resinous layer on a film-shaped resinous substrate;

forming a semiconductor layer on said resinous substrate by plasma CVD; and

forming thin-film transistors, using said semiconductor layer.

5. A method of fabricating a semiconductor device, comprising the steps of:

heat-treating a film-shaped resinous substrate at a given temperature to degas said resinous substrate;

forming a resinous layer on said resinous substrate;

forming a semiconductor layer on said resinous layer by plasma CVD; and

forming thin-film transistors, using said semiconductor layer.

6. A method of fabricating a semiconductor device, comprising the steps of:

heat-treating a film-shaped resinous substrate at a given temperature;

forming a resinous layer on said resinous substrate;

forming a semiconductor layer on said resinous substrate by plasma CVD while heating the resinous substrate to a temperature lower than said given temperature; and

forming thin-film transistors, using said semiconductor layer.

7. A method of fabricating a semiconductor device, comprising the steps of:

heat-treating a film-shaped resinous substrate at a given temperature which is higher than any heat-treatment temperature used in other steps;

forming a resinous layer on said resinous substrate;

forming a semiconductor layer on said resinous substrate by plasma CVD; and

forming thin-film transistors, using said semiconductor layer.

8. An electrooptical device having a pair of film-shaped resinous substrates and a liquid crystal material held between said resinous substrates comprising;

thin-film transistors formed on at least one of said resinous substrates; and

pixel electrodes connected to said thin film transistors,

wherein resinous layers having a planarized surface are formed on said one of said resinous substrates.

[Detailed Description of the Invention]

[0001]

[Industrial Field of Application]

The present invention disclosed in the present specification relates to a configuration of thin-film transistors (TFTs) formed on a substrate having flexibility (i.e. mechanically flexible characteristic) such as a resinous substrate (including industrial plastic substrates). The invention also relates to a method of fabricating such thin-film transistors. Furthermore, the invention relates to an active matrix type liquid crystal display device, using these thin-film transistors.

[0002]

[Prior Art]

Thin-film transistors formed on glass substrates or on quartz substrates are known. Thin-film transistors formed on the glass substrates are mainly used in active matrix type liquid crystal display devices. Since active matrix type liquid crystal display devices can display fine images with high response, it is expected that they can substitute simple matrix type liquid crystal display devices.

[0003]

In an active matrix type liquid crystal display device, one or more thin-film transistors are disposed as a switching element at each pixel. Electric charge going in and out of the pixel electrode is controlled by this thin-film transistor. The substrates are made of glass or quartz, because it is necessary that visible light pass through the liquid crystal display device.

[0004]

On the other hand, liquid crystal display devices are display means which are expected to find quite extensive application. For example, they are expected to be used as display means for card-type calculators, portable computers, and portable electronic devices for various telecommunication appliances. As more sophisticated information is treated, more sophisticated information is required to be displayed on the display means used for these portable electronic devices. For example, there is a demand for functions of displaying finer picture information and moving pictures as well as numerals and symbols.

[0005]

Where a liquid crystal display device is required to have a function of displaying finer picture information and moving pictures, it is necessary to utilize an active matrix type liquid crystal display device. However, where substrates made of glass or quartz are used, various problems take place:

(1) limitations are imposed on thinning of the liquid crystal display device itself;

(2) the weight is increased;

(3) if the thickness is reduced in an attempt to reduce the weight, the substrate breaks; and (4) the substrate lacks flexibility.

[0006]

Especially, card-type electronic devices are required to be so flexible that they are not damaged if slight stress is exerted on them when they are treated. Therefore, liquid crystal display devices incorporated in these electronic devices are similarly required to have same flexibility.

[0007]

[Problems to be solved by the Invention]

The invention disclosed herein aims at to provide an active matrix type liquid crystal display device having flexibility.

[0008]

[Means to solve the Problem]

One available method of imparting flexibility to a liquid crystal display device is to use plastic or resinous substrates which transmit light. However, because of poor heat resistance of resinous substrates, it is technically difficult to form thin-film transistors on them.

[0009]

Accordingly, the invention disclosed herein solves the foregoing difficulty by adopting the following configuration. One invention disclosed herein is characterized by comprising a film-shaped resinous substrate; a resinous layer formed on a surface of said resinous substrate; and thin-film transistors formed on said resinous layer.

[0010]

A specific example of the above-described configuration is shown in Fig. 1. In the configuration shown in Fig. 1, a resinous layer 102 is formed in contact with a PET film having a thickness of 100 μm, the PET film being a film-shaped resinous substrate. Inverted-staggered type thin-film transistors are formed on the resinous layer.

[0011]

The material of the film-shaped resinous substrate can be selected from PET (polyethylene terephthalate), PEN (polyethylene naphthalate), PES (polyethylene sulfite), and polyimide. The requirements are flexibility and transparency. Preferably, the maximum temperature that the material can withstand is made as high as possible. If the heating temperature is elevated above 200℃, oligomers (polymers having diameters of about 1 μm) are generally deposited on the

surface, or gases are produced. Therefore, it is quite difficult to form a semiconductor layer on the resinous substrate. Consequently, the material should have the highest possible processing temperature.

[0012]

In the above-described structure, the resinous layer acts to planarize the surface of the resinous substrate. The planarization also serves to prevent precipitation of oligomers on the surface of the resinous substrate during steps involving heating such as the step for forming the semiconductor layer.

[0013]

As this resinous layer, acrylic resin can be used by selecting from methyl esters of acrylic acid, ethyl esters of acrylic acid, butyl esters of acrylic acid, and 2-ethylhexyl esters of acrylic acid. Even if resinous substrates are used, this resinous layer can suppress the drawbacks with fabrication of the afore-mentioned thin film transistors

[0014].

The configuration of another invention is characterized by comprising the steps of: forming a resinous layer on a film-shaped resinous substrate; forming a semiconductor layer on said resinous layer by plasma CVD; and forming thin film transistors, using said semiconductor layer.

[0015]

The configuration of another invention is characterized by comprising the steps of: heat-treating a film-shaped resinous substrate at a given temperature to degas said resinous substrate; forming a resinous layer on the film-shaped resinous substrate; forming a semiconductor layer on said resinous substrate by plasma CVD; and forming thin film transistors, using said semiconductor layer.

[0016]

In the above-described structure, heat-treatment is made to degas the resinous substrate, in order to prevent degasification from the resinous substrate during later processes involving heating. For example, if gases are released from the resinous substrate when a semiconductor thin

film is being formed on the resinous substrate, then large pinholes are formed in the semiconductor thin film. This greatly impairs the electrical characteristics. Accordingly, the substrate is heat-treated at a temperature higher than heating temperatures used in the later processes, to degas the resinous substrate. In this way, release of gases from the resinous substrate during the later steps can be suppressed.

[0017]

The configuration of a yet other invention is characterized by comprising the steps of: heat-treating a film-shaped resinous substrate at a given temperature; forming a resinous layer on said film-shaped resinous substrate; forming a semiconductor layer on said resinous substrate by plasma CVD while heating the substrate to a temperature lower than said given temperature; and forming thin film transistors, using said semiconductor layer.

[0018]

The configuration of a still other invention is characterized by comprising the steps of: heat-treating a film-shaped resinous substrate at a given temperature which is higher than any heat-treatment temperature used in other steps; forming a resinous layer on said film-shaped resinous substrate; forming a semiconductor layer on said resinous substrate by plasma CVD; and forming thin film transistors, using said semiconductor layer.

[0019]

The configuration of a still further invention comprises: a pair of film-shaped resinous substrates; a liquid crystal material held between said resinous substrates; pixel electrodes formed on a surface of at least one of said resinous substrates; thin-film transistors connected with said pixel electrodes and formed on said resinous substrate; and resinous layers formed on surfaces of said film-shaped resinous substrates to planarize the surfaces.

[0020]

A specific example of the above-described structure is shown in Fig. 3. In the structure shown in Fig. 3, a pair of resinous substrates 301 and 302, a liquid crystal material 309 held between these resinous substrates, pixel electrodes 306, thin-film transistors (TFTs) 305 connected

with the pixel electrodes 306, and a resinous layer 303 for planarizing the surface of the resinous substrate 301.

[0021]

[EMBODIMENT]

[EMBODIMENT 1]

The present example shows an example in which inverted-staggered type TFTs are formed on a substrate of PET (polyethylene terephthalate) which is an organic resin substrate.

[0022]

As shown in Fig. 1(A), a PET film 101 having a thickness of 100 μm is first prepared and heat-treated to degas the film. This heat-treatment is required to be conducted at a temperature higher than the highest temperature applied in later processes. In the processes shown in the present example, a temperature of 160℃ used during formation of an amorphous silicon film by plasma CVD is the highest heating temperature. Therefore, the heat-treatment for degassing the PET film is performed at 180℃.

[0023]

A layer of an acrylic resin 102 is formed on this PET film. As an example, a methyl ester of acrylic acid can be used as the acrylic resin. This acrylic resinous layer 102 acts to prevent precipitation of oligomers on the surface of the PET film in processes conducted later. The acrylic resinous layer 102 also serves to planarize the uneven surface of the PET film. Generally, the surface of PET film has unevenness of the order of several hundreds of angstroms to 1 μm. Such unevenness greatly affects the electrical properties of the semiconductor layer having a thickness of several hundreds of angstroms. Therefore, it is quite important to planarize the base on which the semiconductor layer is formed.

[0024]

Then, gate electrodes 103 of aluminum are formed. The gate electrodes are formed by forming an aluminum film to a thickness of 2000 to 5000Å(3000 Å in this example) by sputtering and performing a well-known patterning step making use of photolithography. The gate electrodes are etched so that the side surfaces are tapered (Fig. 1(A)).

[0025]

Thereafter, a silicon oxide film acting as a gate insulating film 104 is formed to a thickness of 1000Å by sputtering. The gate insulating film may be made from silicon nitride instead of silicon oxide.

[0026]

Subsequently, a substantially intrinsic (I-type) amorphous silicon film 105 is formed to a thickness of 500Å by plasma CVD under the following conditions:

film formation temperature (at which the substrate is heated):160℃

reaction pressure: 0.5 Torr

RF power (13.56 MHz): 20 mW/cm^2

reactant gas: SiH_4

In this example, the film is formed, using a parallel-plate type plasma CVD device. The substrate is heated by a heater disposed within a substrate stage in which the resinous substrate is placed. In this way, the state shown in Fig. 1(B) is obtained.

[0028]

Then, a silicon oxide film which acts as an etch stopper in a later step is formed by sputtering and then patterned to form an etch stopper 106.

[0029]

Thereafter, an N-type amorphous silicon film 107 is formed to a thickness of 300Å by parallel-plate type plasma CVD under the following conditions:

film formation temperature (at which the substrate is heated):160℃

reaction pressure: 0.5 Torr

RF power (13.56 MHz): 20 mW/cm^2

reactant gases: $B_2H_6/SiH_4 = 1/100$

[0030]

In this way, the state shown in Fig. 1(C) is obtained. Then, the N-type amorphous silicon film 107 and the substantially intrinsic (I-type) amorphous silicon film 105 are patterned by a dry-etching process. An aluminum film is formed to a thickness of 3000Å by sputtering. Thereafter,

this aluminum film and the underlying N-type amorphous silicon film are etched to form source electrodes 108 and drain electrodes 109. During this etching process, the action of the etch stopper 106 assures that the source and drain regions are isolated from each other (Fig. 1(D)).

[0031]

An interlayer insulating layer 110 is formed out of a silicon oxide film or a resin material such as polyimide to a thickness of 6000Å. Where a silicon oxide film is formed, an applying solution for forming a silicon oxide film may be used. Finally, contact holes are formed, and pixel electrodes 111 are fabricated from ITO. In this way, thin-film transistors arranged at the pixel electrodes of the active matrix type liquid crystal display device can be fabricated, using the transparent resinous substrate (Fig. 1(E)).

[0032]

[EMBODIMENT 2]

The present example shows a case in which an active matrix type liquid crystal display device is fabricated, using the thin-film transistors described in Embodiment 1. The liquid crystal electro-optical device described in the present example is shown in Fig. 3 in cross section.

[0033]

In Fig. 3, PET films 301 and 302 having a thickness of 100 μm respectively, form a pair of substrates. An acrylic resinous layer acts as a planarizing layer indicated by 303. Indicated by 306 are pixel electrodes. In Fig. 3, only the structure corresponding to two pixels is shown.

[0034]

Indicated by 304 is a counter electrode. Orientation films 307 and 308 orient a liquid crystal 309 which can be a twisted-nematic (TN) liquid crystal, supertwisted-nematic (STN) liquid crystal, or a ferroelectric liquid crystal. Generally, a TN liquid crystal is employed. The thickness of the liquid crystal layer is several micrometers to about 10 μm.

[0035]

Thin-film transistors (TFTs) 305 are connected with the pixel electrodes 306. Electric charge going in and out of the pixel electrodes 306 is controlled by the TFTs 305. In this example,

only one of the pixel electrodes 306 is shown as a typical one but a required number of other configurations of similar structure are also formed.

[0036]

In the structure shown in Fig. 3, the substrates 301 and 302 have flexibility and so the whole liquid crystal panel can be made flexible.

[0037]

[EMBODIMENT 3]

The present example shows an example in which coplanar type thin-film transistors used for an active matrix type liquid crystal display are fabricated. The process for fabricating the thin-film transistors of the present example is shown in Fig. 2. First, a PET film 201 having a thickness of 100 μm is prepared as a film shaped organic resinous substrate. The film is heat-treated at 180℃ to promote degassing from the PET film 201. A layer of an acrylic resin 202 is formed on the surface of the film. In this example, an ethyl ester of acrylic acid is used as the acrylic resin.

[0038]

Then, a substantially intrinsic (I-type) semiconductor layer 203 in which a channel formation region is formed is grown by plasma CVD under the following conditions:

film formation temperature (at which the substrate is heated): 160℃

reaction pressure: 0.5 torr

RF power (13.56 MHz): 20 mW/cm^2

reactant gas: SiH_4

In this example, a parallel-plate type plasma CVD device is used to form the film.

[0039]

Then, an N-type amorphous silicon film is formed to a thickness of 300Å by the parallel-plate type plasma CVD device under the following conditions:

film formation temperature (at which the substrate is heated): 160℃

reaction pressure: 0.5 torr

RF power (13.56 MHz): 20 mW/cm^2

reactant gases: $B_2H_6/SiH_4 = 1/100$

[0040]

The N-type amorphous silicon film is patterned to form source regions 205 and drain regions 204 (Fig. 2(A)).

[0041]

A silicon oxide film or silicon nitride film acting as a gate insulating film is formed by sputtering and patterned to form the gate insulating film 206. Gate electrodes 207 are then formed from aluminum (Fig. 2(B)).

[0042]

A polyimide layer 208 is formed as an interlayer insulating film to a thickness of 5000 Å. Contact holes are further formed. ITO electrodes 209 becoming pixel electrodes are formed by sputtering, thus completing TFTs (Fig. 2(C)).

[0043]

[EMBODIMENT 4]

The present example is similar to the structure of Example 1 or 2 except that the semiconductor layer is made of a microcrystalline semiconductor film. First, a substantially intrinsic semiconductor layer is grown as the microcrystalline semiconductor layer under the following conditions:

film formation temperature (at which the substrate is heated): 160℃

reaction pressure: 0.5 torr

RF power (13.56 MHz): 150 mW/cm^2

reactant gases: $SiH_4/H_2 = 1/30$

In this example, a parallel-plate plasma CVD device is used to form the film.

[0044]

The conditions under which an N-type microcrystalline silicon film is formed are described below. Also in this case, a parallel-plate type plasma CVD device is used.

film formation temperature (at which the substrate is heated): 160℃

reaction pressure: 0.5 torr

RF power (13.56 MHz): 150 mW/cm^2

reactant gases: $B_2H_6/SiH_4 = 1/100$

[0045]

Generally, a microcrystalline silicon film can be obtained by supplying power of 100 to 200 mW/cm^2. In the case of the I-type semiconductor layer, desirable results are obtained by diluting silane with hydrogen by a factor of about 10 to 50, as well as by increasing the power. However, if the hydrogen dilution is made, the film growth rate drops.

[0046]

[EMBODIMENT 5]

The present example relates to a method consisting of irradiating a silicon film with laser light having such a power that the film-shaped base (substrate) is not heated, the silicon film having been formed by plasma CVD as described in the other examples.

[0047]

A technique for changing an amorphous silicon film formed on a glass substrate into a crystalline silicon film by irradiating the amorphous film with laser light (e.g., KrF excimer laser light) is known. In another known technique, impurity ions for imparting one conductivity type are implanted into the silicon film and then the silicon film is irradiated with laser light to crystallize the silicon film and to activate the impurity ions. The silicon film became an amorphous silicon film by implantation of the impurity ions.

[0048]

The configuration described in the present example makes use of a laser irradiation process as described above, and is characterized in that the amorphous silicon film 105 shown in Fig. 1 or the amorphous silicon films 203 and 204 shown in Fig. 2 are irradiated with quite weak laser light to crystallize the amorphous silicon film. If the previously formed film is a microcrystalline silicon film, the crystallinity can be improved.

[0049]

KrF excimer laser or XeCl excimer laser can be used as a laser light. The energy of the irradiation is 10 to 50 mJ/cm^2. It is important that the resinous substrate 101 or 201 be not thermally damaged.

[0050]

[EFFECT OF THE INVENTION]

In an active matrix type liquid crystal display device, the following advantages can be obtained by adopting the invention disclosed herein;

1. the thickness of device itself can be reduced, the weight can be decreased,

2. the substrates do not break if an external force is applied, and

3. flexibility can be imparted to the display.

This liquid crystal display device can find wide application and is quite useful.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Fig. 1 illustrates a process for fabricating thin-film transistors according to the embodiment;

Fig. 2 illustrates another process for fabricating thin-film transistors according to the embodiment; and

Fig. 3 is a schematic cross-sectional view of a liquid crystal panel.

[EXPLANATION OF MARKS]

101, 201	PET film substrate((polyethylene terephthalate)
301, 302	
102, 202	acrylic resinous layer
303	
103, 207	gate electrode
104, 206	gate insulating film
105, 203	substantially intrinsic amorphous silicon film
106	etch stopper layer
107	N-type amorphous silicon film
108	source electrode
109	drain electrode
110	interlayer insulating film
111, 209	pixel electrode

205	source region
204	drain region
304	counter electrode
305	thin film transistor
306	pixel electrode
307, 308	orientation film
309	liquid crystal material